THE GEOLOGY AND MINERALOGY OF IRON ORE DEPOSITS OF TONDA DISTRICT (Jhunjhunu) RAJSTHAN

By
Kr. Pervez Talib
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A_B_S_T_R_A_C_T

The Precambrian rock formations of this area, associated with the iron-ores deposits, belong to the Delhi System which is represented by Alwar and Ajabgarh series. The Alwar formation are not encountered here in this area; only the Ajabgarh formations are developed. The Ajabgarh series is usually argillaceous and mainly composed of schists, quartzites and calc-gneisses. These Ajabgarh formations are intruded by epidiorites and granites.

The strike of these formations is persistent in NE-SW direction. The dips are variable . Two types of faults are also observed (1) Strike Fault ,(2) Transverse Fault. The strike frequency diagram of the joint shows that these rocks have been affected by tectonic forces acting from WSW-&-ENE directions.

The petrographic study of granite shows that the granites are of magmatic origin. The rocks of this region show the highest grade of metamorphism viz., granulite facies. The metamorphism ranges from almandine - amphibolite to granulite facie.

The iron-ore deposits of the Tonda iron mine are of metamorphic origin as it has been revealed by the present, extensive study. The iron-ores are mostly composed of magnetite, ilmenite, hematite and goethite . The textural and mineralogical study of the iron-ores show that originally it was a sedimentary deposit, probably of the composition, Fe_2O_3 variety with sufficient amount of titanium, which was later metamorphosed.

C_O_N_T_E_N_T_S.

P A R T - I - G E O L O G Y & S T R U C T U R E

PART-II IRON ORES.

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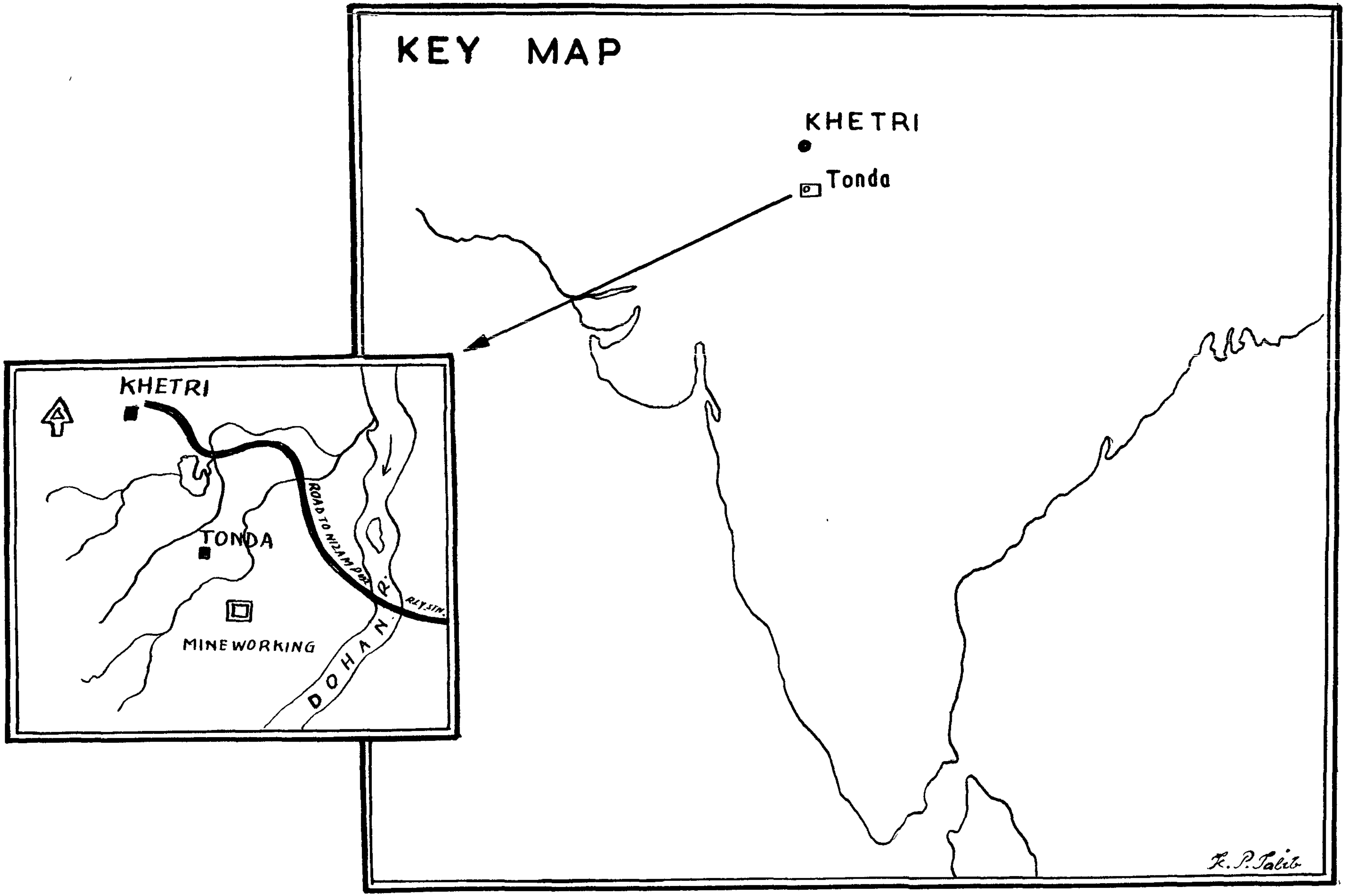

KEY MAP
KHETRI
Tonda
KHETRI
TONDA
MINEWORKING
ROAD TO NIZAMPUR
RLY.STN.
DOHAN R.
K. P. Talib

PART - I

GEOLOGY & STRUCTURE

CHAPTER I

I N T R O D U C T I O N

PURPOSE OF INVESTIGATION:

Location: Tonda is situated in the longitude $75^\circ\ 58'$ and Lalitude $75^\circ\ 56'$ in the Jhunjhunu district of Rajsthan.

Since the region belongs to the oldest rock system of India and structurally and economically it is a rich area hence it was selected for the study. The purpose of present study is as follows:

1. To study the local geology with special reference to structure and stratigraphy of the Precambrian rocks forming the Delhi system around the area.
2. To investigate, mode of occurance, minerology & genesis of the iron ores of Tonda iron mine.
3. To trace the metamorphic history of the area.

Various previous workers have done work in different parts of Rajsthan , but the study of iron ores of Tonda has not been attempted in any detail so far.

METHODS AND TECHNIQUES

The study was carried out under the following heads:

1. Field work including geological mapping of the area mode of occurance & structure of iron ores & systematic sampling of iron ores for megascopic study. Collection of rock samples.

2. Laboratory work including the construction of geological and structure maps of the area and the preparation of polished sections of iron ores and their study under one microscope. Thin section study of rock specimens, & the chemical analysis of iron ores.

The area was geologically mapped in the month of October 1967, The most suitable month for the field work in this area by outcrop walking method with the help of clinometer compass. An area of about 16 sq. miles around Tonda was covered and representative samples of various rock types were obtained from the field, samples of iron ores were also collected from the Tonda iron mines certain other small iron mines of the area. Since parts of the area are covered by alluvium and forests, it was not possible to follow any regular pattern of sampling. However, all the nallas, river cuttings apart from the rocky hillocks were approached and the representative specimens of the different rock types were collected.

The lithological cantacts are not very sharp in this area except in the case of one or two because they are widely covered by alluvium. As such no idea about these burried outcrops could be drawn from the surface. The colour and the pattern of the rock units was also somewhat helpful in differentiating the rock types and their contacts. Shape, slope and vegetation were also helpful upto some extent in mapping the area. Great care was taken in recording the strike and dip of the rock formations.

TOPOGRAPHY, DRAINAGE CLIMATE AND INHEBITANTS OF THE AREA

The topography of the Rajsthan is largely due to the Aravalli system of mountains, stretching in north easterly direction from Champaner in Gujrat in the south-west to close by Delhi in the NE; where it ends in the well known quartzite ridges. From Delhi, in the south-westerly direction, the strike shoots up into a series of detached hills, forming themselves in the first well-marked range near Khetri in Jhunjhunu district with parts of Babai (2,594') Rajhunathgarh (3,450') and Taragarh (2,855'). The hills become more prominent further in the south-west and image in the form of several parallel ranges. Those splaying out to the south and the south east towards Udaipur and Dungarpur, occupy a width of about 30 miles. The main range however continues to proceed in the south west direction, till it ends near the south east corner of Sirohi district beyond the highest peak called Gurushankar(5,650').

The Aravallis which divide the semi-desert of western Jaipur, from comparatively damp and fertile region of the south-east, consist largely of lightly folded and intensely metamorphosed rocks. They are well-developed in the south where they were intruded by the Eranpura granite, Idar granites, Jallore and Siwana granites. They form a synclinorium forming the present mighty mountain system, of the Aravalli range. This system must have risen to a considerable hight and had been rejuvinated in Post-vindhyan times.

From Sambhar to Udaipur the Aravalli form the watershed of rivers falling into gulf of Cambey and Kutch in the West andJamuna-Gangatic system in the east. The tributaries of Mahi and Sabarmati have disected southern Udaipur. There are a few natural and artifecial laks in this region, the largest among them being the Dhabar, 25 miles of SE of Udaipur city.

C_L_I_M_A_T_E

Climates of Rajsthan on the whole is extreme. It is generally very hot and dry in summer. Annual rainfall varies from 5 inches to 35 inches. It is generally very hot and dry in summer while north-western Rajsthan is comparatively cooler than the south-eastern region in winter. The weather is dominated by north westerly and south westerly winds and sandstorms in summer. Taking temperature, rainfall and humadity into consideration, the climate of the north western region is generally hot and dry and comparatively immune from epidemics. Due to sandy nature of the soil which rapidly gets hot during the day and cools down quickly after dusk, variation of temperature is as much as 22°F, noted between maximum and minimum temperatures.

F L O R A & F A U N A

Rainfall, climate, the prevailing winds and the nature of the soil have contributed to the distribution of the flora. Thick (vegetation is to be found in the Aravalli range and the southern plateau. The trees are deep-rooted and thorny with smaller leaves.

The fauna of Rajsthan though limited but well preserved. Among the large mammals the Tiger (Felis Tigeris) is common, Black Buck (Antilope Carvicapra) Chikara, especially Neelgai (Blue Bull) Pig, Sambhar are the common wild life of this region.

P R E V I O U S W O R K

Parts of Rajsthan were mapped originally by Hacket C.A. (see Krishnan 1968) and later by La Touche (1902) and Middlemiss C.S.

(see Krishnan 1960). During the present century a large part of the region was mapped by Heron A.M. assisted by Coulson A.L., Gupta G.C., and Ghosh P.K. and others. The geology has been described in a series of papers and an excellent summery of the work has been given by them.

Heron A.M. (1935) has also described that the Aravallis of Rajsthan are analogus to, if not contamporaneous with the Dharwars of south India, and further he suggested a very general correlation of these rocks with the Dharwars of Madhya Pradesh and Chotanagpur and the Mergui series of Burma.

One further outlier of Aravalli series but this time to the south-west extremity of its strike, was recorded in the vicinity of Baroda near the site of the ancient city of Champaner (Blanford 1869). It spreads over a large area of northern Gujrat and is known as the Champaner series. The component rocks are quartzites, conglomerates, slates, lime stones, all highely metamorphosed.

CHAPTER II

GEOLOGICAL SETTING OF THE AREA

The rocks of this region are supposed to be the most ancient formations of India. One of the most conspecuous features of the ancient rocks is a profound unconformity seperating a highly compressed and metamorphosed assemblage from all overlying set of beds, which generally speaking, are not appriciably folded, and have undergone comparatively little mineral change. The term " Archean" is applied in this work to all rocks which lie stratigraphically below this great " Eparchean" discordance. The beds which normally succeeded being described as Puranas. The term Precambrian used to denote any rock or event which preceeded the Cambrian period and belong either to Archean or Purana group.

All the rock formations here and the adjoining areas are Precambrian in age and belong to Delhi system which was sub-divided into two groups i.e. the Alwar series, is dominently arenaceous. It consists chiefly ofa pile of thick sediments represented by rock types varying in composition from pure orthoquartzites to Arkose. In places these rocks are interbeded with phyllites, schists, marbles and amphibole quartzites.

The other group namely the Ajabgarh series is composed of metamorphosed argillites and represented by various types of schists and phyllites. Schists are interlayered with thick massive quartzites, locally marble and other calc rocks are present.

The contact between the two series is gradational. At many places along this contact, anthophyllite-commingtonite bearing rocks resulting from metasomatism attandant with mineralization are well developed.

According to Heron A.M. (1935) Delhi system lies over the Bundelkhand gneisses and raialos with a great unconformity and in turn overlain by the Vindhyans with an unconformity between the two. The unconformity at its base is taken to represent the post-Archean interval.

The quartzites of both Alwar series and Ajabgarh series, most commonly in the former, show current bedding, ripple marks and locally graded-bedding, which in addition to structural features, greatly aided in determining the stratigraphic sequence of the rocks. The generalized seccession of the Delhi system of Rajsthan is presented below:

	INTRUSIVES:	Ankerite-chert, quartz vein Younger basic dikes Granite, Pegmatite, quartz vein etc Older basic rocks
DELHI SYSTEM	AJABGARH SERIES (about 1300 m)	Marbles, calc-gneisses etc Quartzites, phyllites, schists etc Various types of schists & phyllites
		Gradational Contact
	ALWAR SERIES (about 1300m)	Amphibole quartzites, amphibob gneiss, marbles etc. Arkosic quartzites, quartzites with intercalated phyllites & schists Phyllites & schists

Base not exposed.

The metasediments are intruded by the older amphibolites, granites and the related rocks and followed by the younger basic dikes. The younger basic dikes are tectonically least distributed. Larger bodies of the older amphibolites are mainly scattered over the schistose area. The exposures of the granitic rocks are very small but their genetic relation with the mineralization have made them more significant.

As usual the outcrop data for the study of Aravalli system are scanty owing to the fact that great exposures of it are covered by thick alluvium.

Both the Alwars and Ajabgarh series show more intences of folding and alteration than they do in the country to the east. Further to the west the metamorphism is still greater.

CHAPTER III

STRATIGRAPHY & STRUCTURE OF THE AREA

STRATIGRAPHY: In Tonda area ($75^\circ58$: $75^\circ 56'$) the Delhi system consists principally the upper group the Ajabgarh series. Alwar series was not encountered in the area under study.

The general slope of the planes of the region is south words towards the Sambher lake, but the drainage of nearly all the streams is either absorbed by the sand or hardly reaches the river. Features of relief are due to the exposures of hard Ajabgarh quartzites seperated by comparatively soft Ajabgarh schist again and again in closely pressed folds. The over the outcrops are of two kind (1) Narrow Valley are formed by the removal of easily eroded strata interbedded between the more resistant beds (2) The broader and longer synclinal valley are located on payllites.

In this region the general strike of the rock is NNE---SSW. Dips are always variable between 40°- 70° in the direction of east in the southern portion and in the direction of west in the northern portion. Over folding is friquent indicating that the forces which folded the strata came from the SW or West and tend to form isoclines with their axial planes inclined in these directions. The succession of the rock which have been investigated in these region is as follows:

		Alluvium
INTRUSIVES	(	Pegmatites Granites Epidiorites
AJBGARHS	(	Calc-granulites,Calc-gneisses and impure marbles Quartzites Schists with or without garnet

________Gradational Contact ___________

AJABGARH FORMATIONS

The series of this region is probably between 60,000 to 90,000' in thickness. Covering the whole area. It varies locally in its physical characters but consist pre-dominently of compact quartzites. Generally the quartzites are pure. There is a sill like mass of epidiorite in the north of these quartzite ridges. In the south of the ridges there are bosses of granite with pegmatite veins which are of the same age, occur. In the north of Tonda (75°,58,75°,56$'$) the quartzites are felspathic and little arkosic in nature. In the south they became schistose in nature. The elongated grains of quartz arranged in particular direction.

Generally speaking the Ajabgarh quartzites are grayish white to brownish in colour due to the presence of small amount of iron oxide minerals. They are coarse grained and sub-vitreous, breaking with sub-conchoidal fracture and show sharp splintery edges. Further westword of Tonda (75° 58$'$:75° 56$'$) in the second ridge of the quartzite the flakes of biotite and muscovite with some iron ore are also present.

The quartzites are well jointed in the different systems, namely strike joint, cross joint and diagonal joint. Cross and diagonal joints are more prominent than the strike joint.

Towards south of Tonda (75°58$'$: 75° 56$'$) there is another ridge of quartzite, which is purplish in colour, very compact and massive. The strike here is also in the same direction. NNE---SSW but the dips are higher at the northern flank and lower at the southern flank.

The iron ores have been exploited in the past from the Delhi and older rocks of this series at several places.

The quartz biotite schists are the oldest in this series than comes the quartzites and than calc-gneisses, granulites anc crystalline lime stones. The schists are brown in clour. At the core of the anticline the garnetiferous schist are developed.

At the uppermost part of the series comes the calc-gneisses, purplish green in colour, massive and compect.

Except the quartzite ridges the Ajabgarh of this area exposed typically in a confused expense of low black hummocks. The outcrops bear a sparse scrub jungle, mainly of Euphorbia and other shrubs of similar formidable spineness. In this area the low hills are mainly mica schists with impure dolomitic marble which are often altered to grey crystalline rock with tremolite and actenolite.

The facies of Ajabgarh show the deeper water deposition. Jointing is conspicuous and irregular and weathering produces steep bare ridges with sharp crest and serrate peaks usually black in colour and practically devoid of vegetation.

S_T_R_U_C_T_U_R_E

The most conspicuous structural feature of this area is a series of large doubly plunging folds which with the increasing intensity of deformation, yielded to reverse and normal faults. These fault zones, particularly those developed as a result of reverse faulting, are important as they acted as the main channelways for ore deposition.

Regionally the strike of the formation varies from NNE---SSW to NE--SW with high dips. The major fold axis plunges either north easterly or south westerly, but locally where the effects of superposed folding are pronounced, the axis of two sets of folds may be nearly at right angles to each other. The amount of plunge is generally moderate (25°) but some of the later folds superposed on earlier plunge steeply or sub-vertically. The couse of the large longitudinal doubly plunging anticlins an occupied by the rocks of Ajabgarh series.

Lateral movements due to the faulting are insignificant and most of the faults are dip slip type. The majour faults are located either at the contact of different lithologic units. The faults also run sub-parallel to the strike of the formations.

LOCAL STRUCTURE:

In general the strike in this area running NNE--SSW direction to NE--SW direction. The dips are variable. The attitude of the dip ranging from 45°--70°. In the southern portion the beds are easterly dipping while in the north it is westerly dipping. The are consisting two anticlinal folds and one synclinal fold. The anticlins are tightly compressed while the syncline is broader. The anticline and the syncline are plunging in the SW. direction. The amount of the plunge folds is almost the same. The plunge attitude of the anticline is 25° while the plung attitude of the syncline is 28°.

There are two faults marked in this area, the begger one is the strike slip fault running sub-parallel to the strike while another is the transverse fault.

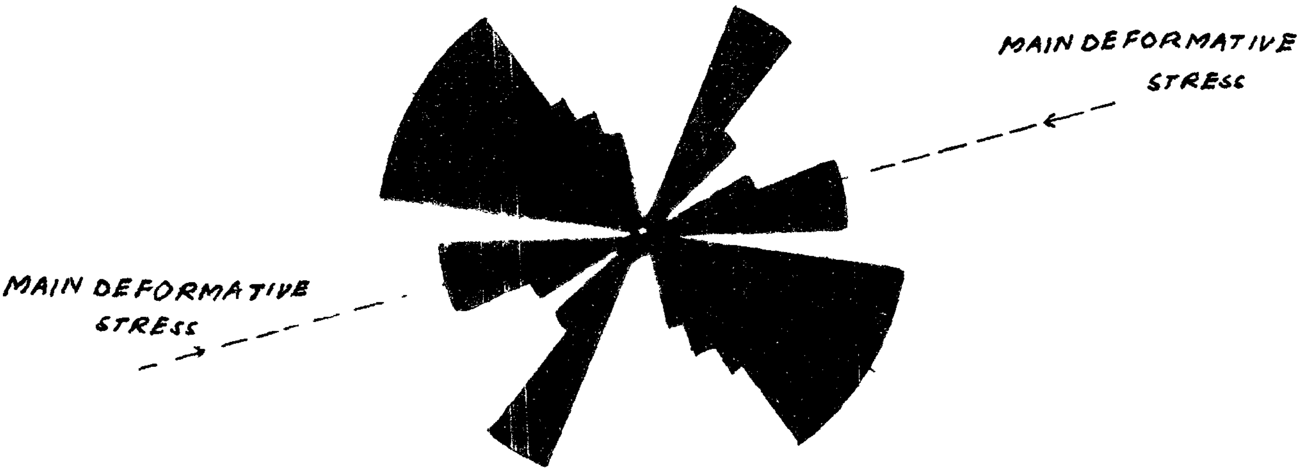
All the three systems of joints are conspicuous in this area namely cross joint, diagonal or oblique joint and the longitudinal joint. The cross and diagonal joints are more prominent than the longitudinal joint. The frequency of joint is given in the diagram.

Depending upon the frequency diagram of the joint pattern we can interprate the structure upto some extent. The trace of the joint indicate the ENE--WSW direction of the principle stress, which produces the main fault in the south of Tonda (75^{o} $58^{'}$: 75^{o} $56^{'}$) between the schists and quartzites, striking NE SW direction. This faulting took place at an earlier stage while the transverse fault in the west of Tonda between quartzites took place at a later stage or in other words, the strike fault is older and the transverse fault is younger in age.

These forces had also folded the strata into complicated isoclinal folds having the axial planes in the NE--SW direction.

STRIKE FREQUENCY DIAGRAM.

SHOWING DIRECTION OF MAIN DEFO-
RMATIVE STRESS IN JOINTS



(JOINTS)

CHAPTER IV

L_I_T_H_O_L_O_G_Y & P_E_T_R_O_G_R_A_P_H_Y

HORNBENDE GRANITE:

Megascopic Observations:

The pink granite are recognised in hand specimen by its colour. It consists of felspars(mostly microcline and orthoclase), quartz and ferromagnisiun minerals.

The potash felspars (microcline and orthoclase) are pink in colour and recognised by their characteristics flesh colour and sub-vitreous lusture. Quartz is white to smokey in colour. The ferromagnesian minerals are Hornblende and biotite.

Microscopic Observations:

Felspars and quarts are the essential minerals of the granite. It is holocrystalline, coarse grained, equigranular showing hypidimmorphic texture. Quartz felspars are 50 and 29 per cent respectively. Felspars are microline and orthoclase, perthite, microperthite and plagioclase. Microcline is very fresh in these granites. Orthoclase is very much kaolinised.

Larger subhedral grains of plagioclase(oligoclase) were observed. They are highely sericitized and exhibit cloudy appearence. Few grains in plagioclase show lamellar twinning.

Biotite, hornblende, magnetite, zircon are the accessaries. Hornblende is dominating among the accessaries, hence ~~xxxx~~ the name hornblende granite is given to this granite. Biotite shows pleochroic colours from light green to dark green. Iron rich biotites show dark colour of pleochroism. Biotite has corroded outlines, but pleocaroic hallows are not seen in these biotites. Hornblendes are green and at some places at the borders altered into chlorites.

Magnetite and sphene are the other minor accessaries.

In microcline the cross hatched twing is well seen. Other plagioclases are very much kaolinized, giving the turbid appearence. Biotite and magnetite are closely associated in these pink granites.

MODEL COMPOSITION OF HORNBLENDE GRANITE

Quartz	30.4%
Orthoclase	29%
Microclene	2.3%
Plagioclase	9.8%

Muscovite	.34%	
Hornblende	1.18%	
Perthite	.7%	
Accessories	6.27%	Total. 100

The model composition shows that rock consists of alkali felspar, quartz and some ferromagnesium minerals. At some places the entire felspar ~~xxxxxxxxxxxxxx~~ grain is altered into kaolin. The dominant felspar is microcline. Plagioclase felspars are sodic and they have blebs of quartz (due to exsolution or replacement) giving rise to myrmekitic intergrowth, quartz grain show wavy extinction. The absence of porphyritic texture is the strongest point in favour of igneous origin of the rock (Plate 2 Fig 1)

C_A_L_C- G_N_E_I_S_S :

Megascopic Observations:

It is fine to medium grained rock, pinkish green in colour. The dark ormafic minerals are alternately arranged in the rock giving to the rock the typical gneissose structure. It is almost equigranular. The flakey minerals are arranged alternately with tabular minerals.

Microscopic Observations:

Felspars and quartz are the essential minerals of these gneisses with alternate bands of mafic constituents (Hornblende a little biotite).

Quartz is found in the form of colourless euhedral to sub-hedral crystals, showing low relief and Ist order polerisation colours. Hornblende is found in the form of green sub-hedral and at some places lath shaped crystals, showing high relief and pleochroism from light green to yellow, showing 2nd order pol. colours and 30^{o} extinction angle.

Composition of plagioclases ranges from oliogoclase to andesine. Plagioclases shows twinning common of albite law.

There is quite a good range of accessary minerals. Microcline,magnetite, apatite, titanaugite and a few crystals of zircon.Microcline shows low relief,Ist order polarisation colours and polysynthitic twinning, one according to albite law and the other according to peri-cline law. Another accessary mineral is titanaugite, titanaugite is hardly distinguished from sphene, the only difference is that of crystal shape and the former is slightly pinkish in colour. Apatite is found in form of characteristic minute prismatic six sided crystals,showing moderate relief and usually in orientation the crystal is length fast, and recognisable by parallel extinction. Chlorite is another accessary mineral which is found in very minute quantity.(Plate II Fig.2).

There are alternate bands of falsic and mafic minerals in addition of hornblende and a good amount of magnetite a little titanaugite and apatite shows that the rock has experienced regional metamorphism.

Q_U_A_R_T_Z_I_T_E_S:

Megascopic Observations:

It is greyish white in colour, very coarse grained, massive showing vitreous lusture and conchoidal fracture.

Microscopic Observations:

Under microscope it is very coarse grained and shows granoblastic texture, with equant grains inter-locking with each other. The shape of the grains are euhedral and it is phaneratic rock. Chief constituents is the quartz. Accessary minerals are magnetite and small amount of sericite. Quartz in these quartzites show strain shadows and sutured boundries. Sericite is found along the borders of quartz grain in a very little amount.

The grain size of the rock, sutured boundries of the quartz grain and inter-locking arrangement, and strain shadows in the quartz grains show that they have been subjected to regional metamorphism. All these characters give an idea that they are formed by the contact of regional metamorphism of sandstones.

SCHISTOSE QUARTZITES:

Another type of quartzites which is found in this area is schistose.

Megascopic Observations:

The quartzites are purplish in colour, medium grained, hard and compact.

Microscopic Observations:

It is medium grained. The elongated quartz grains are oriented parallel to one another. They are characterised by thepresence of muscovite, sericite, and some iron oxides hence the name schistrose quartzites has been given to this quartzites. Quartz grains show interlocking texture and wavy extinction. Rest of the properties are the same as that of the previously described quartzite (Plate II Fig. 3.).

The presence of the elongated grains oriented and muscovite and sericite along with iron oxide gives to the rock a schistose structure. This indicates that they were subjected to stress. The presence of strain shadows in quartz is also an evidence of the strain. Presence of accessary minerals such as muscovite sericite and iron oxides is an evidence of regional metamorphism.

FELSPATHIC QUARTZITES:

A third variety of quartzites found in the north is felspathic quartzites.

Megascopic Observations:

It is white in colour, medium grained, hard massive and compect.

Microscopic Observations:

Under microscope it shows granoblastic texture with equant grain, interlocking each other. The percentage of felspars 15 per cent observed by point counting method. Hence the name felspathic quartzites is given to these quartzites. (Plate II Fig. 4.).

QUARTZ BIOTITE SCHIST:

Megascopic Characters:

It is brown in colour, very loosely compect, mica flakes are easily distinguishable by the naked eye, well foliated.

Microscopic Observations:

Under the microscope, the general observation is that the mafic minerals are dominent and secondly that of quarts.

This rock consists mainly of green and brown biotite. Chlorite, hornblende and magnetite are among the accessories.

It is medium grained and almost equigranular. The flaky minerals are oriented giving to the rock schistose structure. Biotite shows one set of cleavage (Plate Fig. 1) and maximum obsorption parallel to the direction of lower polaroid. Quartz found in between the flakes of biotite, having the low relief and wavy extinction. Characteristics are that of the normal quartz. One or twocrystals of hornblende are also there. The extinction angle of hornblende vary from 16^{o}--20^{o}. hornblende is sometimes found to be in altered form.(Plate III Fig. 1).

MODAL COMPOSITION OF QUARTZ - BIOTITE SCHIST

Biotite	Quartz	Hornblende	Chlorite	Acc.	Total
32.2%	43.6%	8.5%	7.9%	8.07%	100.00

Garnet has been developed in the core of the anticline in quartz-biotite schist having the pinkish,Almandite variety of garnet.

CALC-GRANULITES:

Magascopic Observations:

Pinkish green in colour, green mineral is found in aggregates in the rocks of pink colour. Medium grained, massive and compect. In hand specimen the pink portion is that of felspars (orthoclase).

Microscopic Observations:

Calcite and the orthoclase are the essential minerals. Calcite is found in quite a good amount, hence the name calc-granulite is given to this rock. Quartz is in very minor amount. Orthoclase is completely kaolinised. Among the potash felspars another mineral is microcline which is poorly represented in very minute crystals. Among accessory minerals there is some pyroxen (Aegirines) which is the dominant among accessories. It is green and strongly pleochroic to x, darkgreen y, lightgreen z, yellow, found in long prismatic crystals mostly and some basal sections are also seen. Longitudinal section show 2^{o} extinction angle and length fast character. The other accessory minerals are magnelite and zircon, ilmenite.

Texture: Granoblastic Texture.Plagioclase usually not zoned and have turbid cores. (Plate III Fig. 2)

C_O_N_C_L_U_S_I_O_N : Presence of kaolinised orthoclase, calcite, granoblastic texture, aegirine, ilmenite, magnetite and zircon gives the other evidences that they are formed by deep seated regional metamorphism under very high temperature and pressure (granulite facie) conditions.

IMPURE MARBLE:

Megascopic Observations:

Brownish grey in colour crystalline, compect and hard, gives the effervecences with the acid, but the effervenence is not very vigorous indicating that the marble is impure.

Microscopic Observations:

These marbles consist predominently of calcite, and tremolite and actinolite as the essential constituents. Among the other common accessories they include apatite and magnelite.

Texture vary considerably in some specimens of marbles in which the carbonate minerals are arranged in an equigranular granoblastic mosaic. While in other specimens more commonly the grains have irregular denticulate margins and tend to form an interlocking to complexly sutured aggregates. Twin lamellae are conspicuous, as is rhombohedial cleavage. In calcite the twin lamellae are parallel to the sides of cleavage rhomb or bisect only the acute angle of the cleavages.

Presence of calcite, tremolite indicate that they are formed either by the contact and regional metamorphism of lime stones.

EPIDIORITE:

Megascopic Observations:

It is medium to fine grained greenish grey in colour. hard and compect.

Microscopic Observations:

The epidiorite is a homogenous granuletic non porphyritic and schistose rock consisting chiefly of hypidiomorphic green hornblende with interstitial quartz and clear felspar. Hornblende showing 22^{o} to 30^{o} extinction.

Hornblende is the predominent constituent,highly pleochroic from dark green to yellowish green. Quartz found in sub-hedral form in between the spaces of hornblende left. Felspars are found in minor amounts (Plate III Fig. 4.).

PEGMATITES:

The pegmatites of this area may be considered as quartz pegmatites, biotite pegmatites and felspar pegmatites. Megascopically these pegmatites consist of quartz, biotite and felspars. These pegmatites are found in the form of lenses almost everywhere in the area (Plate III Fig. 3.).

IGNEOUS INTRUSIVES.:

The gneisses and quartzites are conspicuously injected by veins of quartz and pegmatites especially, the gneisses to whcih the pegmatites are practically confined.

The greater hardness and lesser fissility of quartzites present mechanical impedient to igneous intrusions. Beside the pegmatite there are granite bosses near Desurda (26°,10': 76° 5'). They are supposed to be invading the Ajabgarh, usually rising from the alluvium. These are the hornblende granits, which occur as bosses. This type of granits form the chief intrusive igneous rock in the Delhi system.

According to Heron A.M.(1935) these graints are that of Post-Delhi age, and graint and pegmatite have the same magnetic origin and are both intrusives.

Pegmatites, like the epidiorites are distributed almost all over the area. They are practically sbsent from the quartzite probably owing to the greater extent to which the later offered resistence to the forces causing intrusions. They form the masses of all sizes from the small fractions of an inch to many yards, especially in the form of lenses along the strike. They very in grain from medium to coarse.

The mineral constituents are quartz, microcline, orthoclase, muscovite and tourmaline. Tourmaline at some places vary in size from a fraction of an inch to one foot long and 3-4 inches in diameter. The quartz is characteristically intergrown with microcline and orthoclase texture is graphic. One lense of pegmatite is found near Mewara ($27^{\circ},10'$:$75^{\circ},49'$). Another big lense of pegmatite with considerable size of tourmaline crystals found near Tonda ($75^{\circ},58'$: $75^{\circ}56'$) along the northern side of the quartzite ridge in the Ajabgarh schists, and a few small lenses here and there in the rocks.

According to Heron A.M.(1935) there are two phases of pegmatite intrusions. The acid pegmatite veins which form interfolear injections in the gneisses and schists of Ajabgarhs, probably belong to the early phase, since they seem to be effected to some extent by the folding. The later comes the large well crystallized masses of coarse pegmatite bearing muscovite and tourmaline, exhibit no compression effect some places cut through the gneiss as in Mewara ($27^{\circ},10'$: 75° $49'$) and are independent of the structure traversed later.

According to Anden (1933) the intrusion of some of the pegmatite presumably those of the earlier phase preceeded the formation of shear zone, and the gneissification of the granite took place about the same time, as the shearing, but the crystallisation occured later.

In the northern portion of the area near Banowas ($76^{\circ},58'$: $74,56^{\circ}$). There is an enormous mass of epidiorite. Near the country rock it is fine grained but in the middle it is coase grained. The strike and dip of this intrusion are almost the same as that of country rock. Here the thick mass of epidiorite formed rounded hillocks of lesser hight, and rich soil not unlike the black cutton soil. It consists predominently of amphibole, quartz and felspars. These epidiorites are hamogenuous granuletic non-porphyritic and schistose rock consisting chiefly of hypidiomorphic green hornblende.

Heron A.M. (1935) considered the epidiorites to be contemporenous with the meta-sediments. Latter it was folded with the sediments.

Quartz vening is not often observed in the Ajabgarh except where they have been much crushed. Deposits of calcite are recorded from fissurs in Ajabgarh quartzites in this area. Heron (1935) described the Rajsthan deposits as occuring in vein filling fissurs which must have opened long after the formation of quartzites. The calcite of Ajabgarh series therefore would seem to belong to a later geological phase than that of the intrusive granites and pegmatites, to which it is probably totally unrelated in origin.

M E T A M O R P H I S M

The metamorphic rocks of this area consists of schists, quartzites anc calc-granulite. They represent regionally metamorphosed products of pre-existing argillaceous sediments. The assemblage of pelitic rocks are characterised by tremolite,chlorite, biotite, garnet felspars-quartz with little iron oxide minerals.

Metamorphic mineral assemblages of the area described here with the increasing grade of metamorphism. The following are the typical mineral assemblages, charactersing the grade of metamorphism in the area.

Muscovite: Usually occur in the form of small flakes. It is a low grade metamorphic mineral, occuring in quartzites, disappear with the increasing grade of metamorphism, when it reacts with biotite and quartz yield almandine garnet.

Chlorite: Chlorite occur in schists in the form of fine grained aggregates but in minor amount. The variety of chlorite found is penninite.

Amphiboles: The amphiboles (iron and magnesium) of the area are characterised by extreme irregularity in the form of small crystals and in the form of porphyroblasts. The amphiboles have been replaced by chlorites in the gneisses and calc-granulites. These amphiboles altered to biotite, at some places into chlorite and also in magnetite.

The tremolite and actenolite occur in the impure marbles. Small tabular flakes of biotite are found in most of the rocks. It is also replaced by chlorite shows the increase in grade of metamorphism.

Garnet: Faintly pinkish variety of garnet (almandite) found in the garnetiferous schists. This garnet is formed in the garnetiferous schists in the core of the anticline. Show the mineral was formed due to the stress and high temperature.

By the study of these rocks present in the area gives an evidence that the rocks here are not original representatives but ~~the~~ are deformed reconstituted representatives of the original rocks.

The above mentioned studies was made on the lines of Barrow (1893) Grubenmann (1904) Terner Verhoogan(1961). Das Gupta (1961,1962,1964) suggested that the pelitic rock assemblage belong to the highest facie of Tarner Verhoogan ie. almandine-amphibolite facie to granulitefacie.

In this area the mineral assemblages are the products of regional metamorphism. The presence of almandine garnet and granulites itself indicating the highest grade of metamorphism.

P A R T - II

I R O N - O R E S

CHAPTER V

I R O N O R E S

INTRODUCTION:

In this part mineragraphic study of the iron ores of Tonda ($75^{\circ}58'$: $75^{\circ}56'$) are of district Jhunjhune NE Rajsthan is investigated. The iron ores of this area are generally associated with Delhi quartzites and calc-granulites of precambrian age. Based on their physical characters the iron ores are grouped into four varieties. Ore microscopic study led to the identification of hematite, goethite, magnetite and ilmenite. Some intresting micro-structures were observed in the iron ores. The iron ores of this area are of two types viz (1) Magnetic (2) Non-magnetic.

The iron ore deposits of this area failed to receive the adiquate attention of earlier workers. It is however, obvious that neither any authoritative geological and nor mineralogical account of ore deposits is available to date. Heron A.M. (1935) referred the nature and mode of occurance of iron ores of Rajsthan without referring to this deposit. Nothing about this deposit was also given by Krishnan M.S. (1954).

According to Krishnan M.S.(1954). the iron ores were being worked out at several places in the district of Alwar, Jaipur, from the Aravalli lime stones. Delhi quartzites and hornstone breccias of precambrian age. In the general report of Geological Survey of India fro the year 1959 (Roy 1962) it has been reported that Subramaniam M.R. and Mahapatra M.K. of the Indian Beareau of Mines, examined the iron and manganese ore bearing areas of Rajsthan. They demarcated the areas suitable for exploitation. They have also visited some of the iron mines of this area also, but no mention was made in the report about the iron ores of Tonda.

Recently Mukherjee A.D.(1966) Department of Geological Sciences Jadavpur University has also performed some work on the allied area in Khetri ($28^{\circ}00''$:$75^{\circ}0'0''$) and Paprona (27° $55'$ $55''$: 75° $48'$ $20''$) in the Jhunjhunu district of Rajsthan.

MODE OF OCCURENCE

The iron ores of this iron mine are particularly associated with calc-granulites of Delhi system. Here the calc-granulites have the same strike and dip as that of the country rock i.e. NNE--SSW and dipping 50° due East. Here the mining operation has also been done by some private company and the length of the ore body is estimated about 20 feet. Here the ore body is found in the form of isoclinal fold. The dip of the right limb of the fold is 35° while that of the left limb is 16°. It is in the form of plunging fold which is plunging in the NW direction, the attitude of the plunge is 32°.

The ore found here in this ore body in the form of bands, which contain the massive magnetite deposits. In between the ore band there is a thin band of country rock (Plate I Fig. 1). Each band is 5-6 feet thick. The mining started here from the nose of the plunging ore body and done up to the core of the isoclinal fold. The attitude of the fold is about 60 feet. To exploit the ore two banches were also made on the upper side of the isoclinal fold. Each banch has a length of 150'--200'

C_L_A_S_S_I_F_I_C_A_T_I_O_N

Depending on their physical nature the iron ores have been grouped as follows:

(1) HARD & MASSIVE ORE: Dark steel coloured, compect massive ore having the metallic lusture-forming dense clusters in the band. Fairly magnetic.

(2) HARD & SCHISTOSE: Fine to medium grained variety with dark to steel grey colour with black spots of gangue oriented in a particular direction, viseble under low power magnifying lense.Melallic lusture, slightly magnetic.

(3) HARD & CRYSTALLINE ORE: This variety of ore is very common found in most of the mines of this area. It is very crystalline and by hammering it readily falls into crystalline grains. It is dark grey in colour. Very lustu-rous or the fresh surface show good metallic lusture.

M_I_N_E_R_A_L_O_G_Y

So far as the iron ores ares are concerned, hematite, magnetite, ilemenite and goethite are the most important iron minerals. The identification of the iron ores was completed partly by their physical characters and partly by optical properties under reflected light.

(1) HEMATITE: (Grey iron ores)

It occurs mostly as fine grained steel grey ore with even fractures and lusturous surface. It is metallic grey in colour. Hardness 5.5-6 streak grey, specific gravity quite high.

(2) MAGNETITE: (Dark grey and magnetic iron ore)

One variety of magnetite occur in the granular and crystalline aggregates. There is another variety in which irregularly arranged and deformed aggregates of dark grey crystals are there. Magnetite rich samples are iron black in colour, lusture metallic . Hardness 5.5-6.0. They are strongly magnetic. Specific gravity high.

Ilmenite: (Dark Grey non-magnetic iron ores)

It is found in the form of dense, black grains in the grey aggregate of magnetite and hematite visible by the naked eye. These grains are haphazardly arranged in the ore some times form the dense clusters. Showing the dull metallic lusture. Hardness 5.6-6.1 streak black non-magnetic which distinguish it from magnetite.

Ochreous Limonite: It is yellow ochre or yellow ore, very soft and powdry type, very fine grained found generally in the weathered ore around the grains of fresh ore in very minor quantity.

M I N E R A G R A P H Y O F T H E O R E S

Polished sections of the iron ore samples of Tonda and other mines of the same area, were studied in the laboratory under the ore microscope to examine the mineralogical characters of the opaque minerals. The identified ore minerals are magnetite, hematite,Ilmenite, goethite and martite.

MAGNETITE:

Magnetite is dominent in some specimens and occur in less quantity in others. It is granular idiomorphic.

produce magnetite and ilmenite along their cleavage planes and along the boundries of magnetite.

MARTITE: Martite is nothing but pseudomorphs of hematite after magnetite. The mineral is granular and the grains vary in size. They commonly occur as idiomorphic, well developed octahedral crystals few of them have fragmentary relic or unreplaced magnetite. Replacement texture is quite common here. The physical and optical characters of martite are almost identical with hematite.

GOETHITE: Goethite is usually found in some weathered ores under reflected light it is non-crystalline,massive dull grey in colour, anisotropism not distinct. It is usually recognised by the internal reflection, because it is found in the very minute quantity along the borders of the hematite grain. Reddish brown internal reflection.

M I C R O T E X T U R E S

REPLACEMENT TEXTURE:

The replacement texture have been observed in some ores, containing goethite,ilmenite, martite and they are as follows:

1. Replacement of magnetite by martite
2. Replacement of ilmenite by hematite
3. Replacement of magnetite by goethite

REPLACEMENT OF MAGNETITE BY MARTITE:

The granular magnetic ore which are martitized to varying degrees, show pseudomorphic replacement textures. The pseudomorphs of martite after magnetite show three sets of lamellae resembling widmanestatten--like texture under cross nicols (see Edward 1960) show a remanent of partly martitized magnetite; having very irregular outline.(Plate. V Fig. 2).

Replacement of Ilmenite by Hematite:

Ilmenite often show replacement along their cleavage planes by hematite. The lamellae of hematite in ilmenite are distinct under cross nicols, these lamellae show anisotropism while ilmenite is isotropic (Plate. V Fig. 3).

REPLACEMENT OF MAGNETITE BY GOETHITE:

The evidence of replacement by goethite was recorded in another variety of magnetite ores in which there are goethite, martite and magnetite. Martite has been derived from magnetite by the partial pseudomorphic replacement of the later as in the previous case of replacement. Goethite was also seen replacing magnetite partially along its outer borders (Plate V Fig. 3).

GRANULAR TEXTURE:

The variety of iron ore in which crystalline magnetite and martite occurs shows granular texture. The closely interlocked and partially martitized magnetite crystals are medium to fine grained in size and polygonal to sub rounded in shape.(Plate. IV Fig. 1

PARAGENESIS:

The siquence of deposition, or paragenesis, of ore mineral in a particular deposit, can be determined in part from hand specimens, but a full understanding of it and of the process involved, can be obtained only from a study of mineral textures, as revealed in polished sections under ore microscope.

To determine the paragenesis of the ore, it is necassry to establish the sequence of formation of every mineral in the ore from their textural and structural relations.

SIMULTANEOUS DEPOSITION:

Where the concentration of the solute mineral was high, such seggregation result more or less granular, allotriomorphic texture, in which the two minerals show smooth, regularly curving contacts, without very decided projections of one mineral into the other (Plate I Fig. 3), the so called " Mutual boundries" texture. Here ilmenite and magnetite show smooth regularly curving contacts or the "mutual boundries" of ilmenite and magnetite are sharp and smooth is the indicative of the simultaneous crystallization of ilmenite and magnetite. Another evidence of the simultaneous deposition is that there is no well developed projection of any of the two minerals into another. This is also an indicative of simultaneous deposition.

SUCCESSIVE DEPOSITION:

Successive deposition is proved if one mineral can be shown to occur as veins transecting the other mineral or to replace it or to be moulded on it. Here we get the veins of hematite or the ex-solution lamellaes of hematite cutting across the ilmenite crystal (Plate. V Fig. 1) and at other places hematite is moulded upon ilmenite and magnetite (Plate. V Fig. 3) and at some places ilmenite and magnetite have the convex sides outwords towards hematite and martite is also the indicative of successive deposition. Similarly the goethite formed at the borders of magnetite and hematite in very minor amount is also indicate that the goethite replaced magnetite and hematite later.

Keeping the above evidence in mind it may be concluded that the magnetite and ilmenite are formed contemporaneously while the replacement and supergene ores ig. hematite (martite) and goethite occured at the later stage.

The paragenetic sequence of the ore-minerals may therefore be presented as follows:

PARAGENETIC SCHEME

	Metamorphic ores	Replacement and Supergene ores
Magnetite	----------------	
Ilmenite	-------------	
Hematite	----	--------
Goethite		----

TIME -------------------------------------

CHEMICAL ANALYSIS OF IRON ORES:

The chemical analysis of the iron ores was done by the author himself in the department of Chemistry, Aligarh Muslim University, Aligarh by the gravitative analysis method. The results obtained are as follows:

Data of Chemical analysis of iron ores

Specimen No.1.	Fe:	64.374%
	Silica:	5.725%
	Al:	15.102%
Specimen No.2.	Fe:	62.7%
	Silica :	6.876%
	Al:	13.47%
Specimen No.3.	Fe :	61.837%
	Silica :	8.241%
	Al :	12.3641%

G E N E S I S OF T H E I R O N O R E S

On the basis of mineralogical and textural studies including the order of formation and the associated country rock of the iron ore, an attempt has been made to account for the origin of the iron-ores as follows:

(1) It has been observed by the mineralogical and textural studies that these iron-ores are composed usually of magnetite with subordinate amount of ilmenite,hematite and goethite in minor amounts. The order of formation of the iron ores is shown in the peragenetic scheme viz. magnetite is the earliest followed by ilmenite,hematite goethite in successive order.

(2) The ores associated with calc-granulites and magnetite schists.

(3) The deposits are found in the banded forms, each band is 5-6 feet thick and four bands are recorded. The ores are mostly found in two types viz. (i) Massive,(ii) granular. The gangue associated with the deposit is insignificant and formed of silica. The author has so far not come across any deposit of this nature outside the area of investigation in this country.

The El Pao deposits of Venezuela are supposed to be that of metamorphic origin (Kalliokoski,J. 1965) are very much similar in many respects to deposits of Tonda.

The El Pao deposits are found in the form of bands, such type of bandsare is also seen here in Tonda iron deposits.(2) The ores of El Pao are found in granulite, here we also get the ores in granulite. The El Pao ores experienced high grade of dynamothermal metamorphism & stress.

The effects of dynamothermal metamorphism and stress are also clear in the iron-ores of Tonda iron mine.

DISCUSSION:

(1) Originally it was sedimentary deposits probably of the composition of Fe_2O_3 variety (Hematite) with sufficient amount of Titanium, as it is in the case of the country rock having some titanium bearing silicates such as sphene and titanaugite.

(2) A high grade metamorphism may be possible cause of conversion of hematite into magnetite ilmenite ore. Contact metamorphism may have also played an important role in the formation of deposits. The evidence of the dynamothermal metamorphism of ironoxide consists of the following facts:

(a) The hard coarse grained iron ores and iron formations occur as layers or (bands) in pyroxene granulites.

(b) The course grain size of the iron-ore itself suggests an environment conducive to substantial recrystallisation.

(c) Lamellar hematite in ilmenite idiomorph is known also from Yampa Sound iron-ores(see Kalliokoski,J.1965) which is demonstrably a dynamothermally metamorphosed iron-ore. The same type of hematite lamellaes are also found in ilmenite of the iron-ores in this area.(Plate. V Fig. 1).

(d) Physical deformation of iron-ore can be seen in microscopic texture (Plate.V Fig. 4.).

(e) Hard iron-ore is folded isoclinally

(3). The absence of chemical alteration and weathering may also be explained as due to the complete metamorphism and stability of the minerals, under the existing weather condition. The non-porous and compact nature of the ore perhaps prevented any easy flow of the meteoric water through the main body of ore.Moreover there is no evidence of brecciation and fracturing of ores on such a scale as to facilitate chemical alteration of the deposits.

(4) Minor alteration are restricted to the surface of the deposit and they are mostly in the form of hydrated iron oxide such as lemonite and goethite. The absence of any rock resembling banded hematite quartzite rules out the possibility of the formation of ore under the condition in which most of the replacement iron-ore deposits of India are formed

CONCLUSION:

These iron-ores are classed as the Metamorphic magnetic iron-ore deposits. Since in the classification of iron-oresof India presented by Krishnan M.S.(1951) this type of deposit has no place,therefore,it may be treated as a distinct group formed by high grade regional metamorphism. The field and laboratory evidences suggest its original sedimentary nature.

Since the deposit is small and uneconomical although it is a high grade iron ore containing 62-65% iron and very low percentage of silica (or gangue) and due to the absence of any steel plant near by, the iron ore deposits of this area failed to receive an adiquate attention of earlier exploiters.

The need for further exploiration by geological and geophysical methods of the area which may lead to the discovery of large reserves of iron-ores of similar high grade in their utilization for industrial development of Rajsthan.

SUMMARY & CONCLUSION

The conclusion derived from the detailed study of Geology, structure,metamorphism,patrography of rocks and the ore microscopic study of iron-oxide ores, may be summarized briefly. The Precambrian rock formation of the area under investigation belong to the Delhi system of Heron (1923).He divided the system into Alwar and Ajabgarh series. The Alwar Serie is not encountered in this region only the Ajabgarh formations are developed. The Ajabgarh series is composed of metamorphose sediments represented largely by schists quartzites andgneisses. These formations were included by epidiorite on one side and by the granites on the southern side of the area. Recently Sikka,D.B. (1964) suggested a geosynclinal origin of the rocks of this area.

The strike of the rocks in this region in NE-SW direction,they have variable dips towards west in the southern side while towards east in the northern side of the area. The folds are plunging in WSW direction and the amount of the plung is almost the same ie. 25-28^{o}. The faults are classed in two types (1) Strike Faults,(2) Transvers Faults. Joints are very conspicuous in this region and geometrically classified as longitudinal joint, cross joint and diagonal joint . The strike frequency rose diagram shows that these rocks have been effected by the tectonic forces acting from NE-NS.

The petrographical account,based on megascopic and microscopic character of rocks. The petrographic study of the granite of the area has revealed that the granite is of megmatic origin.

The study of metamorphism was done in this region of pelitic assemblages and it was found possible to draw isogrades of increasing regional metamorphismm Save the sericite quartzites and felspathic quartzites, the rest of the rocks show the highest grade of regional metamorphism i.e.almandine amphbolite to granulite facie.

The iron deposits are supposed to be that of metamorphic origin the iron-ores are found in the coarse grain bended forms.

The ores are mostly composed of magnetite ilmenite, hematite and goethite. The ores are generally characterised by such textures as replacement and granular.

R_E_F_R_E_N_C_E_S.

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E X P L A N A T I O N OF P L A T E S.

PLATE-I
F I E L D P H O T O G R A P H S

Fig. 1. Banded Megnaetite ore.
Fig. 2. Brecciated ore, in the core of the isoclinal fold.
Fig. 3. A view of the Tonda Iron Mine.
Fig. 4. Quartzites ridge.
Fig. 5. Top-most bench of Iron Mine.

PLATE - II

P H O T O M I C R O G R A P H S

Fig. 1. Granite showing hypidiomorphic, equigranular texture.
Fig. 2. Gneiss of Ajabgarh Series.
Fig. 3. Schistos quartzites of Ajabgarh Series showing elongated quartz grains and sutured boundries.
Fig. 4. Felspathic quartzites , quartz grains showing inter-locking structure.

PLATE- III
P H O T O M I C R O G R A P H S

Fig. 1. Quartz biotite schists,showing schistose structure.
Fig. 2. Calc-granulite,showing kaolinised orthoclase, pyroxene and abundance of magnetites.
Fig. 3. Pegmatite showing the lacks of muscovite and biotite crystals showing zoning.
Fig. 4. Epidiorite showing basal and longitudnal crystals of hypidiomorphic hornblende.

PLATE-IV
P H O T O M I C R O G R A P H S

Fig. 1. Megnatite showing granular texture.
Fig. 2. Magnatite schist showing schistose structure

Fig. 3. Fractured ore.
Fig. 4. Replacement texture,magnetite crystals are surrounded by hematite.

PLATE- V

P H O T O M I C R O G R A P H S

Fig. 1. Ex-solution lamellaes in ilmenite crystal.Martitisation of magnetite is also clear.
Fig. 2. Pseudomorphs of martite after magnetite.
Fig. 3. Magnetite crystal is surrounded by hematite showing replacement texture.Sharp boundries of hematite and magnetite are also clear. Ilmenite crystals is also surrounded by hematite.
Fig. 4. Hematite crystal showing deformation effect.

FIELD PHOTOGRAPHS

PLATE NO. I

Fig. 1

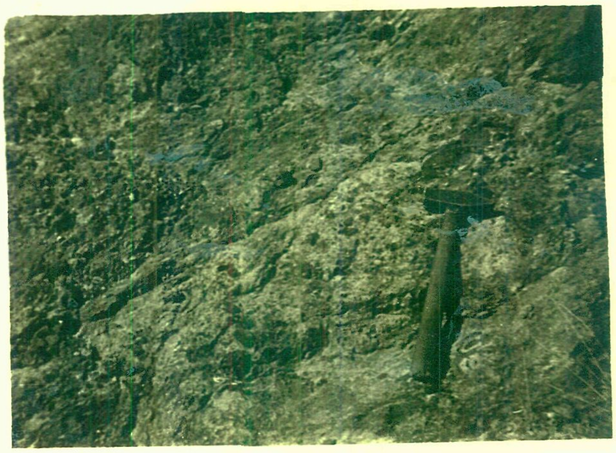

Fig 2

Fig 3

Fig 4.

Fig 5.

P_H_O_T_O M_I_C_R_O_G_R_A_P_H_S

PLATE II

Fig. 1 Crossed nicols x 40

Fig 2 Crossed nicols x 40

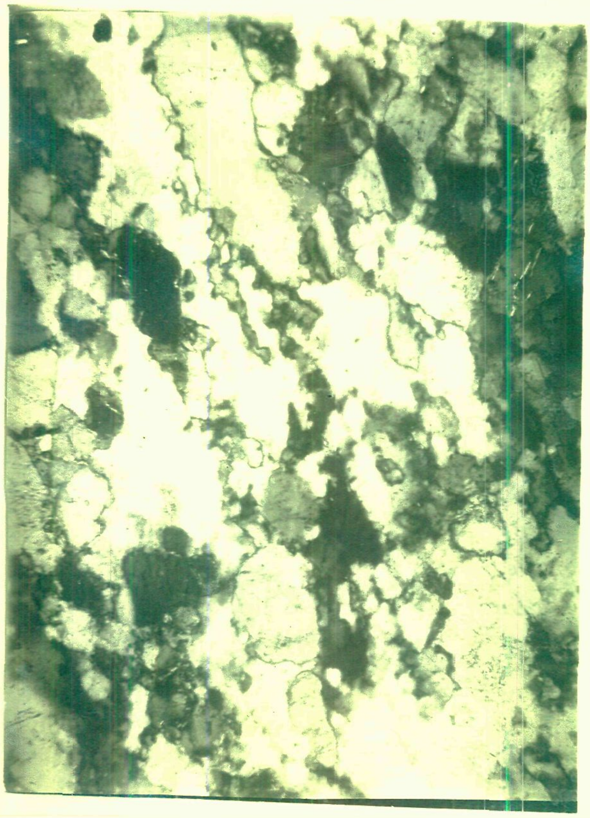

Fig. 3. Crossed nicols x 40

Fig 4. Crossed nicols x 40

PLATE III.

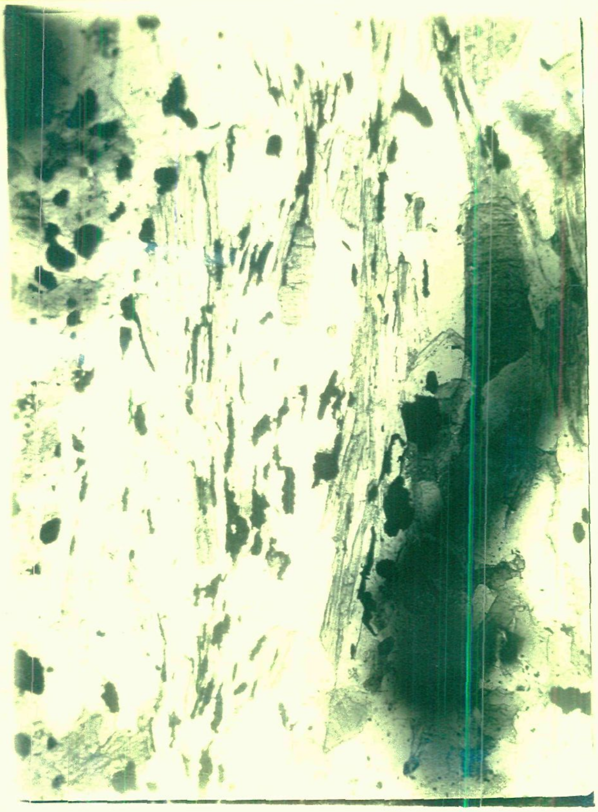

Fig 1 Ordinary Light x 40

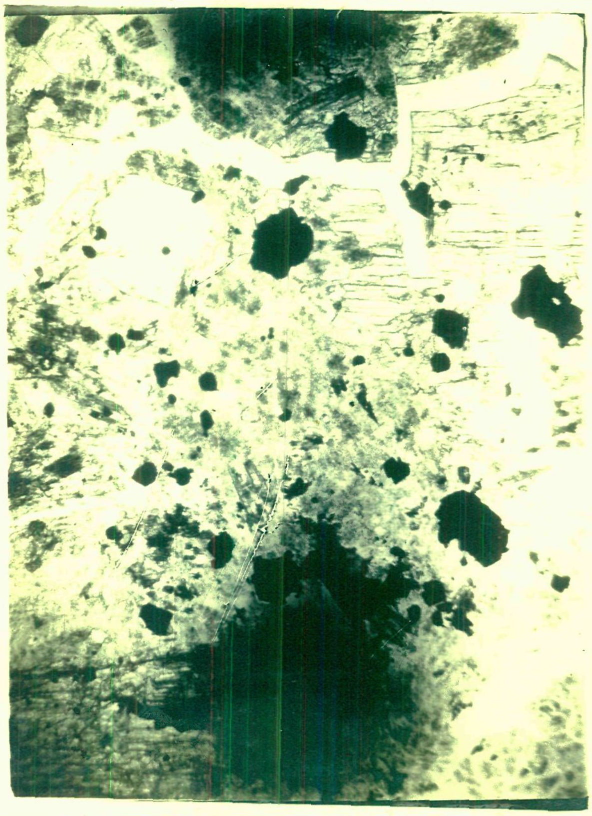

Fig 2 Ordinary Light x 40

Fig 3. Ordinary Light x 40

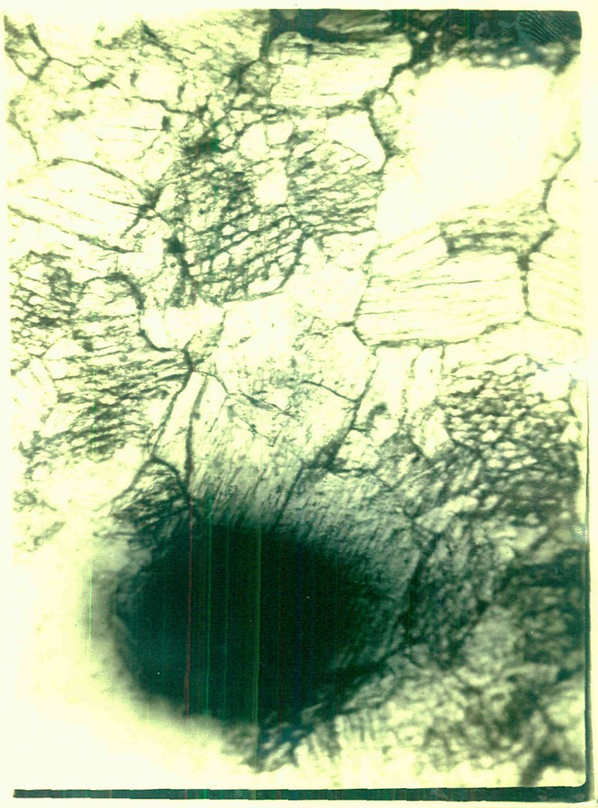

Fig 4. Ordinary Light x 40

PLATE IV

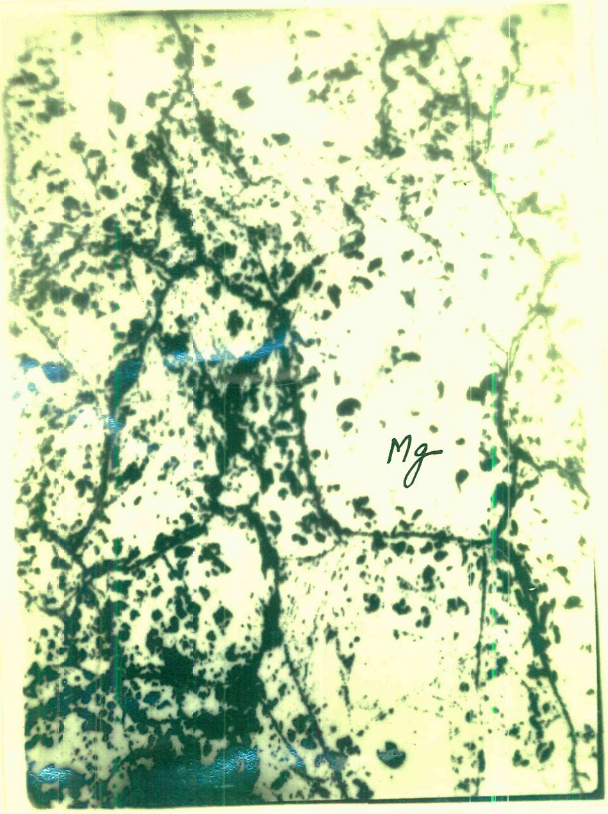

Fig. 1 x 40

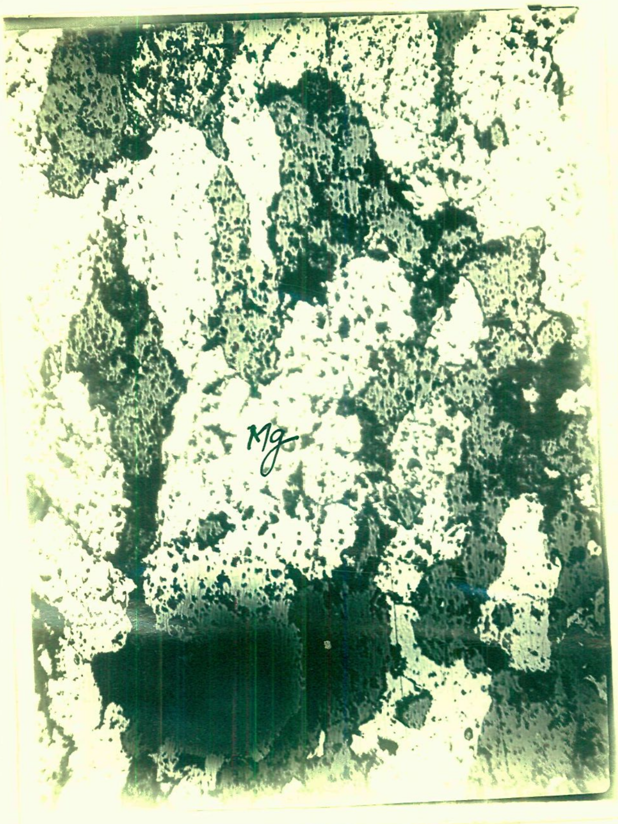

Fig 2 x 40

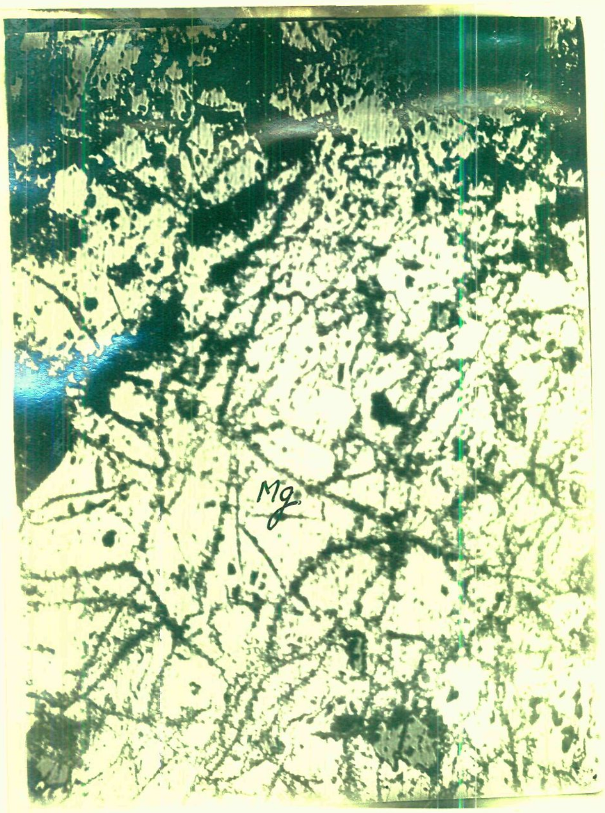

Fig. 3 x 40

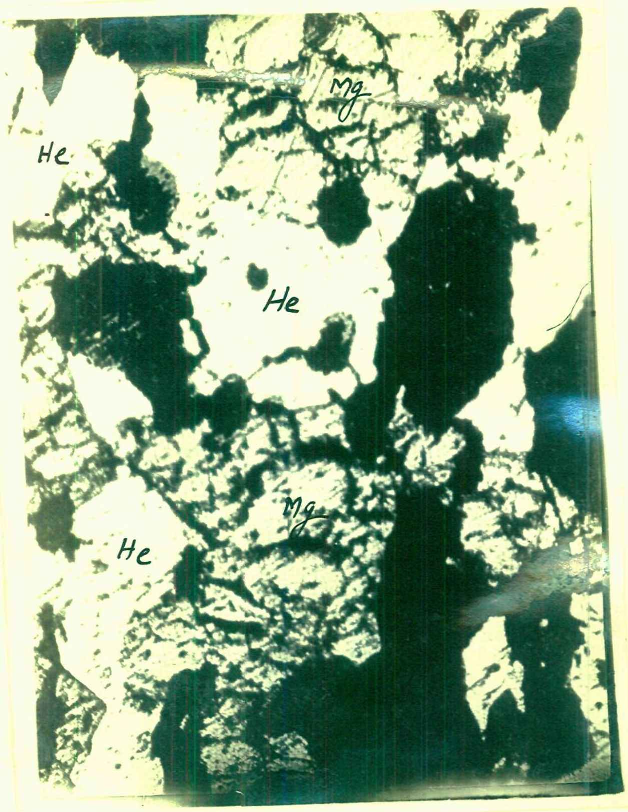

Fig 4. x 40

PLATE V

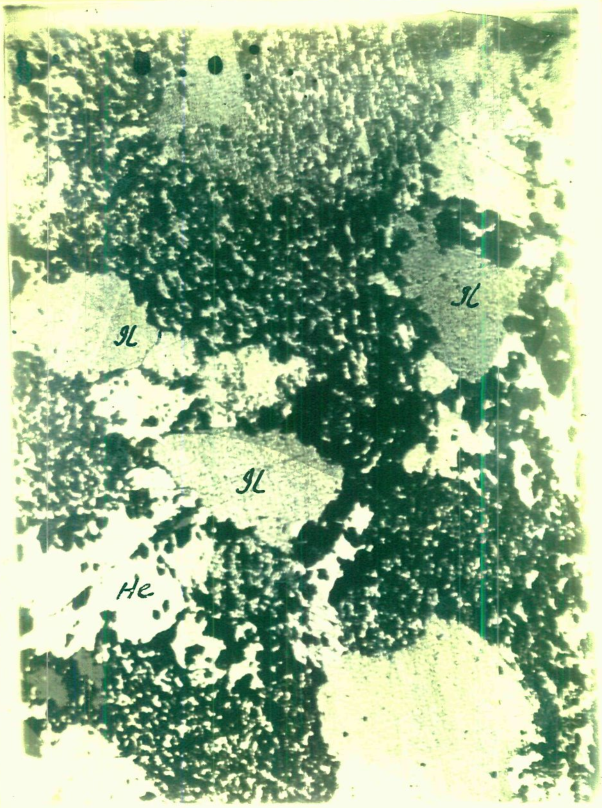

Fig. 1 x 40

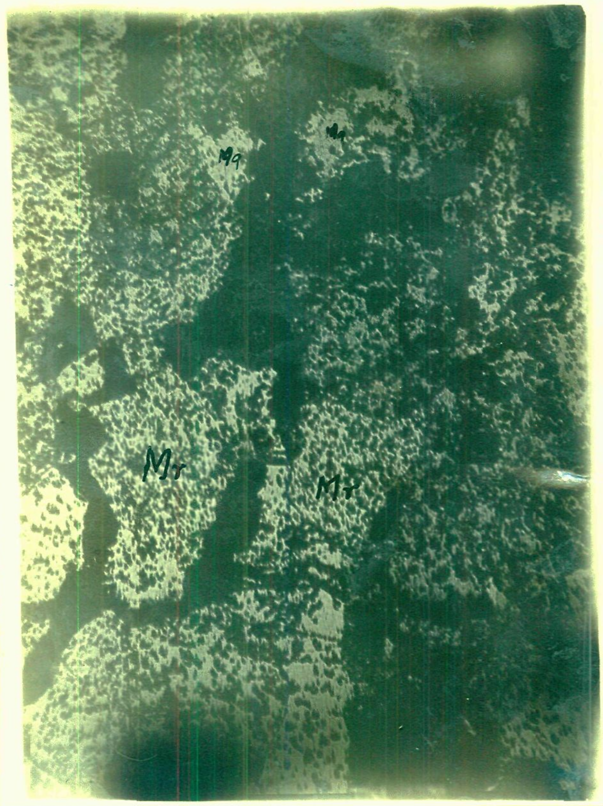

Fig 2 x 40

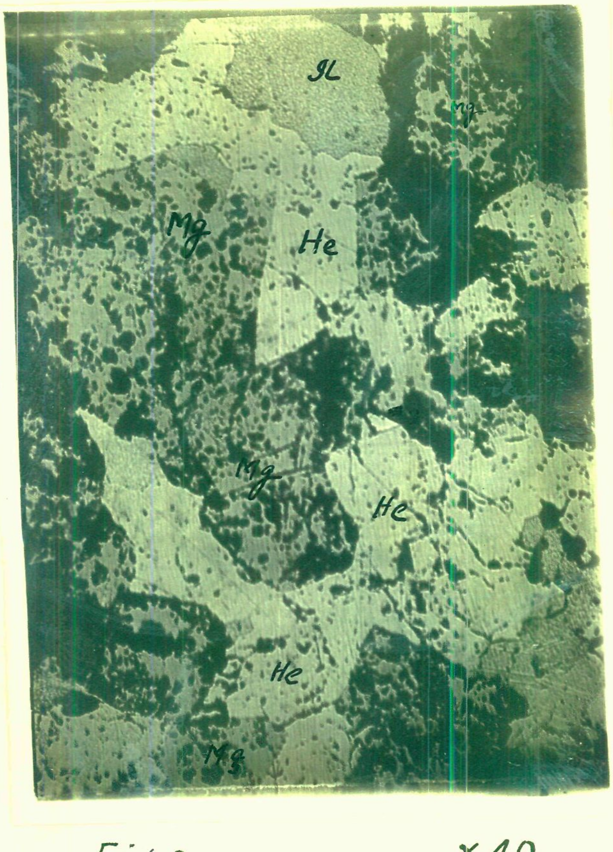

Fig 3 x 40

Fig. 4. x 40